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Fuzzy rule based enhancement in the SMRT domain for low contrast images

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Abstract

Fuzzy techniques offer a new and flexible framework for the development of image enhancement algorithms. They are nonlinear, knowledge-based and robust. The potentials of fuzzy set theory for image enhancement are still not investigated in comparison with other established methodologies. In this paper, an examination of fuzzy methods in transform domain is considered. Fuzzy rule based contrast enhancement in the Sequency based Mapped Real Transform (SMRT) domain for block level processing is explored. SMRT, being an integer transform, is computationally efficient and the fuzzy rule based technique is applied to the entire blocks in the transform domain.

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Keywords: Image enhancement; Sequency based Mapped Real Transform (SMRT); Fuzzy rule based contrast enhancement; Enhancement metrics

1. Introduction

Image enhancement is usually a preprocessing step in many image processing applications. Its aim is to accentuate relevant image features that are difficult to visualize under normal viewing conditions and thereby facilitating more accurate image analysis. It encompasses different spatial and transform domain techniques to improve brightness, increase contrast, sharpen edges, smoothen the region of interest etc.

Majority of image enhancement techniques are developed in the spatial domain. However, for efficient storage and transmission, images are being represented in the transform domain in compressed format. Usually spatial domain methods are applied before compression or after decompression. Enhancement before compression may reduce the compressibility of the original image by altering its statistics. Image enhancement done directly in the compressed domain eliminates the need for additional decompression and compression steps before transmission.

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Many linear and nonlinear methods were used for image enhancement in the transform domain. A simple linear image enhancement method, based on Sequency based MRT (SMRT), was suggested[1] which scales the SMRT coefficients uniformly. Implementation of algorithms involving nonlinear techniques are challenging.

Many nonlinear techniques were developed in Discrete Cosine Transform (DCT) domain. Tang[2] proposed an algorithm based on contrast measure, defined as the ratio of high frequency and low frequency contents in the bands of the DCT matrix. Kim & Peli[3] developed an MPEG based image enhancement algorithm for people with low-vision and contrast enhancement is performed by modifying the inter and intra quantization matrices in the decoder. Lee[4] presented an algorithm for dynamic range compression and contrast enhancement of images under noisy environment. DC and AC coefficients of DCT matrix are modified based on retinex theory and spectral content measures respectively. Challenging aspect of DCT based block level enhancement techniques are the blocking artifacts and inability to enhance all image blocks equally.

Now a days, fuzzy theory has obtained greater popularity in the area of image enhancement. They are nonlinear, knowledge based, can manage vagueness efficiently and offer a suitable framework for the development of new methods. They can process imperfect data if this imperfection originates from vagueness and inherent variability rather than randomness.

Fuzzy rules efficiently process data by mimicking human decision-making. It typically includes a group of antecedent clauses that define conditions and a consequent clause that defines the corresponding action. Thus a fuzzy system is formed by a set of rules that represent the knowledge base of the system and an appropriate inference mechanism that numerically processes the knowledge base to yield the result.

A set of fuzzy IF-THEN rules together with an inference engine, a fuzzifier and a defuzzifier form a fuzzy rule-based system. Several variants of fuzzy systems are available; among them, the most widely used are the *Mamdani fuzzy inference systems* (characterized by the presence of fuzzy sets over the input and output data spaces) and the *Takagi-Sugeno fuzzy inference systems* (input data space is described by fuzzy sets, but the output data space is characterized by singleton sets). Of the two, Takagi-Sugeno fuzzy systems are appealing for their simple forms and the simplicity in computational requirements.

Florea[5] introduced fuzzy-rule based enhancement in the compressed domain. The DCT based algorithm decompresses and pixel level processing is done for those blocks whose AC energy exceeds a certain threshold. For other blocks, enhancement using fuzzy-rule based enhancement is done in the compressed domain itself.

A block level SMRT based contrast enhancement algorithm using fuzzy rule based approach is proposed in this paper. The enhancement algorithm processes the image completely in the transform domain. The quantitative evaluation of the image enhancement technique is performed using Second Derivative like MEasurement (SDME)[6,7], measurement of enhancement (EME)[8] and Image Enhancement Metric (IEM)[9]. SDME is shown to have better performance than other measures in evaluating the image visual quality after enhancement while the blind-reference metric, EME and full-reference metric, IEM measure contrast in a better way.

Organization of the paper is as follows. Section 2 describes the basics of SMRT. Fuzzy rule based Image Enhancement in spatial and transform domain is outlined in Section 3. Algorithm for enhancement is presented in Section 4. Simulation results are given in Section 5 and conclusions are drawn in Section 6.

2. SMRT

Mapped Real Transform (MRT) helps to do the frequency domain analysis of signals without any complex operations and SMRT is sequency ordered form of unique MRT coefficients. MRT representation is evolved from Discrete Fourier Transform (DFT)[10,11] by exploiting the periodicity and symmetry properties of twiddle factor and grouping data.

MRT coefficients[12], $Y^{(p)}_{k_1,k_2}$ of an image $x_{n1,n2}$, $0 \leq n_1, n_2 \leq N-1$, are expressed as

$$Y^{(p)}_{k_1,k_2} = \sum_{\forall (n_1,n_2)|z=p} x_{n_1,n_2} - \sum_{\forall (n_1,n_2)|z=p+M} x_{n_1,n_2} \tag{1}$$

$0 \leq k_1, k_2 \leq N-1$, $0 \leq p \leq M-1$, $z = ((n_1k_1 + n_2k_2))_N$ and $M = N/2$.

2-D MRT maps an $N \times N$ matrix into M matrices of the same size. Thus MRT in the raw form will have $N^3/2$ coefficients and is highly redundant. Unique MRT (UMRT)[11,13] is developed to remove redundant elements present

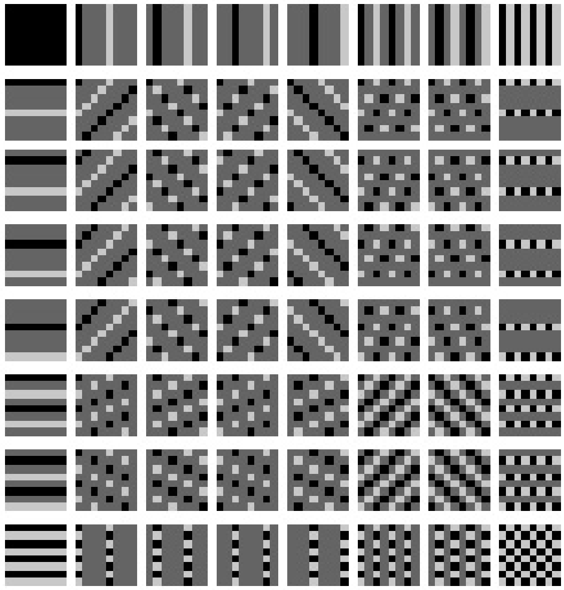

Fig. 1. 2-D SMRT basis images for N=8.

in MRT representation and arranges the N^2 unique MRT coefficients in an $N \times N$ matrix. The N^2 unique MRT coefficients are placed in the order of sequency along horizontal, vertical and diagonal directions to derive sequency based representation named SMRT [14]. Set of 64 basis images corresponding to the 2-D SMRT, for $N = 8$, are shown in Fig.1, where black, white and mid-gray boxes correspond to +1, -1 and 0. SMRT computation of an image employs only integer additions and is hence computationally efficient compared to other transforms.

The coefficient S(0,0) of the SMRT matrix is called DC coefficient and is the sum of all image pixel values. It gives an indication of the image mean and holds most of the image energy. The remaining $(N^2 - 1)$ coefficients represent the intensity values of the image pixels in various patterns and are termed as AC coefficients.

3. Fuzzy Rule based approach

The fuzzy rule-based approach is a powerful and universal method for many image processing tasks. It encodes knowledge about a system in statements of the form- *IF* (a set of conditions) are satisfied *THEN* (a set of consequences) can be inferred.

3.1. Fuzzy rule based contrast enhancement in pixel domain

Fuzzy image enhancement is basically a question of whether a pixel should become more bright or dark than it already is. In fuzzy theory, gray level intensity (r) of an image can be described by three linguistic terms *Dark*, *Gray* and *Bright*, described by suitable membership functions such as triangular, trapezoidal, bell shaped etc. Trapezoidal membership functions can be used for *Dark* & *Bright* and triangular shaped membership functions for *Gray* as illustrated in Fig. 2(a) with corresponding linguistic output variable (r_o) as *Black*, *Midgray* and *White*. When Takagi-Sugeno fuzzy rule based system is used, outputs can be represented as fuzzy singletons denoted by r_o^b for *black*, r_o^g for *mid gray* and r_o^w for *white* is shown in Fig. 2(b).

The general algorithm for fuzzy rule-based enhancement is

- Initialization of the parameters.
- Fuzzification of gray levels.

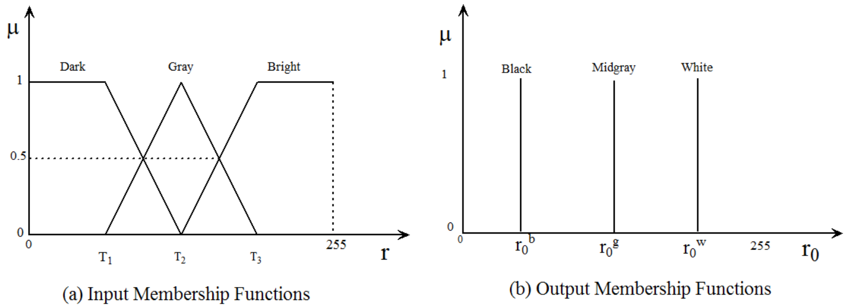

Fig. 2. Membership functions for fuzzy rule-based contrast enhancement

- Inference procedure for evaluating appropriate rules
  (For example, if r & r_o denote input and output variables,
  - Rule 1: If r is *dark* then $r_o = r_o^b$ is *black*
  - Rule 2: If r is *gray* then $r_o = r_o^g$ is *midgray*
  - Rule 3: If r is *bright* then $r_o = r_o^w$ is *white*)
- Defuzzification of the output using three singletons, r_o^b, r_o^g & r_o^w as shown in Fig. 2(b) (eg. $r_o^b = r_{min}$, $r_o^g = r_{mean}$, $r_o^w = r_{max}$).

$$r' = \frac{\mu_{dark}(r).r_o^b + \mu_{gray}(r).r_o^g + \mu_{bright}(r).r_o^w}{\mu_{dark}(r) + \mu_{gray}(r) + \mu_{bright}(r)} \tag{2}$$

Let the dynamic range of r for 8-bit image representation be [0;255]. Trapezoidal function, $f : r \rightarrow [0; 1]$, is selected for representing the input fuzzy set membership functions generally and is shown in Fig. 3.

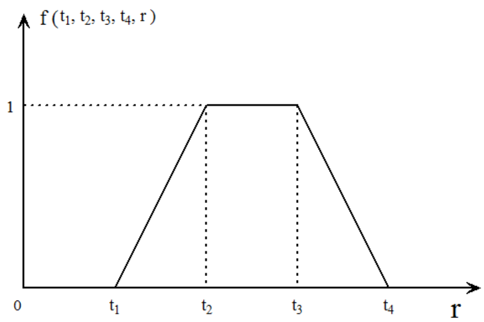

Fig. 3. Trapezoidal function for representing the input membership functions

The function, f, is written analytically as

$$f(t_1, t_2, t_3, t_4, r) = \begin{cases} 0, & \text{if } 0 \leq r < t_1 \\ \frac{r-t_1}{t_2-t_1}, & \text{if } t_1 \leq r < t_2 \\ 1, & \text{if } t_2 \leq r < t_3 \\ \frac{t_4-r}{t_4-t_3}, & \text{if } t_3 \leq r < t_4 \\ 0, & \text{if } t_4 \leq r \leq 255 \end{cases} \tag{3}$$

Hence, the membership function μ for *dark*, *gray* and *bright* can be expressed in terms of f as

$$\begin{aligned} \mu_{dark}(r) &= f(0, 0, T_1, T_2, r) \\ \mu_{gray}(r) &= f(T_1, T_2, T_2, T_3, r) \\ \mu_{bright}(r) &= f(T_2, T_3, 255, 255, r) \end{aligned} \tag{4}$$

Modified gray level values can be obtained from Eq. 2 by proper selection of r_o^b, r_o^g & r_o^w .

3.2. Fuzzy rule based contrast enhancement in transform domain

Average brightness and contrast of an image can be varied by changing its DC and AC SMRT coefficients. Here, the DC and AC coefficients of block level SMRT are modified separately for improving the brightness and contrast respectively. Two constants, necessary for multiplication and addition (v_m^z and v_a^z, $z \in \{dark, gray, bright\}$), are to be found from the parameters t_1, t_2, t_3, t_4 and average brightness of each block. DC SMRT coefficient of a block, $S^B(0,0)$, gives the average brightness of the block. $v_m^z = f'(t_1, t_2, t_3, t_4, S^B(0,0))$ & $v_a^z = f''(t_1, t_2, t_3, t_4, S^B(0,0))$ can be expressed as

$$f' = \begin{cases} 0, & \text{if } 0 \le S^B(0,0) < t_1 \\ \frac{1}{t_2 - t_1}, & \text{if } t_1 \le S^B(0,0) < t_2 \\ 1, & \text{if } t_2 \le S^B(0,0) < t_3 \\ \frac{-1}{t_4 - t_3}, & \text{if } t_3 \le S^B(0,0) < t_4 \\ 0, & \text{if } t_4 \le S^B(0,0) \le 255 \end{cases} \tag{5}$$

$$f'' = \begin{cases} 0, & \text{if } 0 \le S^B(0,0) < t_1 \\ \frac{-t_1}{t_2 - t_1}, & \text{if } t_1 \le S^B(0,0) < t_2 \\ 1, & \text{if } t_2 \le S^B(0,0) < t_3 \\ \frac{t_4}{t_4 - t_3}, & \text{if } t_3 \le S^B(0,0) < t_4 \\ 0, & \text{if } t_4 \le S^B(0,0) \le 255 \end{cases} \tag{6}$$

$$\begin{aligned} v_m^{dark} &= f'(0, 0, T_1, T_2, S^B(0,0)) \\ v_m^{gray} &= f'(T_1, T_2, T_2, T_3, S^B(0,0)) \\ v_m^{bright} &= f'(T_2, T_3, 255, 255, S^B(0,0)) \end{aligned} \tag{7}$$

$$\begin{aligned} v_a^{dark} &= f''(0, 0, T_1, T_2, S^B(0,0)) \\ v_a^{gray} &= f''(T_1, T_2, T_2, T_3, S^B(0,0)) \\ v_a^{bright} &= f''(T_2, T_3, 255, 255, S^B(0,0)) \end{aligned} \tag{8}$$

The comparison with DC SMRT coefficient alone is performed for each of the 8×8 image blocks. The value of $S^B(0,0)$ in each block falls in any of the 5 ranges given in Eqs. 5 & 6. Thus for each block, the constants v_m^z & v_a^z, $z \in \{dark, gray, bright\}$ required to multiply SMRT coefficients and to add DC SMRT coefficient are computed.

Let M^z, $z \in \{dark, gray, bright\}$ be the matrices of membership values of the 8×8 block of the SMRT coefficients, S. These values can be computed as

$$\begin{aligned} M^z &= v_m^z . S \\ M^z(0,0) &= M^z(0,0) + v_a^z \end{aligned} \tag{9}$$

The fuzzy rule-based contrast enhancement method in pixel domain as given in Eq. 2, reformulated in the SMRT domain can be described by

$$S_{mod} = M^{dark} . r_o^b + M^{gray} . r_o^g + M^{bright} . r_o^w \tag{10}$$

where S_{mod} is the modified SMRT blocks.

4. Algorithm

- Image is divided into non-overlapping blocks of size 8×8 and the corresponding SMRT matrices, S are obtained.
- Approximate image histogram is constructed from the block mean values.
- r_{min}, r_{mean} & r_{max} of the histogram are found and the values are assigned to r_o^b, r_o^g & r_o^w.
- For each block,
  - SMRT, S is computed.
  - v_m^z, v_a^z, $z \in \{dark, gray, bright\}$ are found using Eqs. 7 & 8.
  - Membership matrices, M^z, $z \in \{dark, gray, bright\}$ are found using Eq. 9.
  - SMRT coefficients are modified using Eq. 10.
  - Inverse SMRT is computed.

5. Result and Analysis

Experimental results of the fuzzy rule based technique in SMRT domain (FRBS) is applied to both general and medical images. Fuzzy INT operator based image enhancement (FINTP) in the pixel domain [15], is used to compare the effectiveness of the proposed method.

Mammograms are usually not well defined and detection of hidden objects are important in the early detection of breast cancer. The local regions under suspect are normally low in contrast. Enhancement of such low contrast image areas would help radiologists in interpreting data correctly and result in proper diagnosis. Mammogram images from Mini-MIAS digital mammography database [16] are used for analysis.

A few general and mammogram images enhanced using FINT & FRBS are displayed along with respective original images in Fig. 4. Enhanced images show that there is better contrast improvement for FRBS. Enhancement metrics SDME [6,7], EME [8] and IEM [9] are compared for FINTP and FRBS in Table. 1. Since SDME and EME are blind reference metrics, they are computed for original image also.

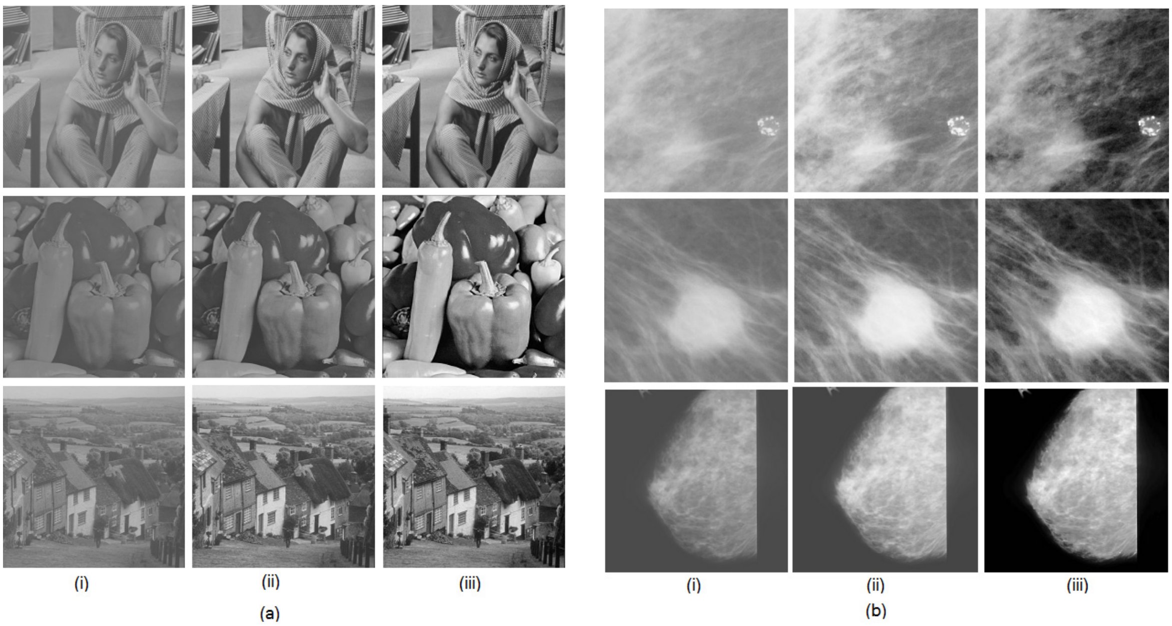

Fig. 4. (a) (i) Original general images (*barbara, peppers, goldhill*) (ii) Enhanced images using INT operator in the pixel domain [15] (iii) Enhanced images using proposed method; (b) (i) Original mammogram images (*mdb119, 028, 219*) (ii) Enhanced images using INT operator in the pixel domain [15] (iii) Enhanced images using proposed method.

Table 1. Comparison of quantitative metrics.

Image	SDME			EME			IEM	
	Original image	FRBS method	FINTP method	Original image	FRBS method	FINTP method	FRBS method	FINTP method
barbara	81.4	133.4	91.99	2.60	6.32	4.75	13.69	9.84
peppers	84.2	179.4	109.8	0.97	6.07	1.84	23.89	10.17
goldhill	87.0	116.3	89.9	2.05	5.70	3.82	14.39	9.83
mdb119	94.9	132.9	105.7	0.98	4.38	1.77	18.00	9.74
mdb028	55.6	144.5	70.0	0.49	2.37	0.58	6.55	3.07
mdb219	99.0	132.9	107.1	0.82	4.27	1.48	18.97	10.46

6. Conclusion

A fuzzy rule based image enhancement in the SMRT domain is proposed. The algorithm hence derived is tested on both general and medical images. The results are compared with that of the fuzzy INT operator based enhancement technique in the pixel domain. SDME, EME and IEM metrics are used to quantitatively assess the visual quality and contrast. Experimental results show that the proposed algorithm works well quantitatively and qualitatively in both general and medical images.

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